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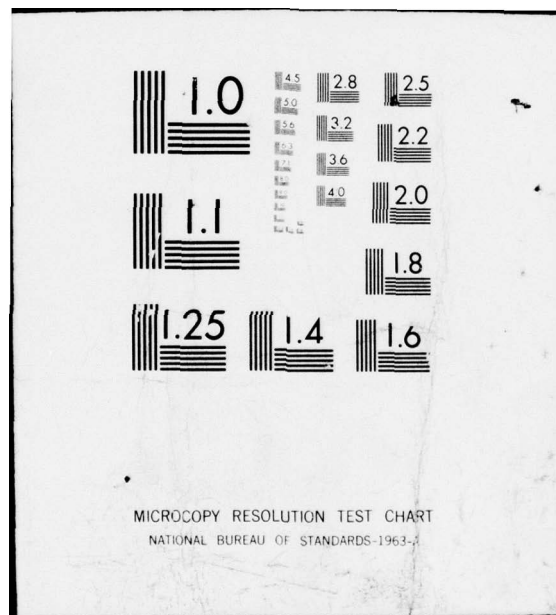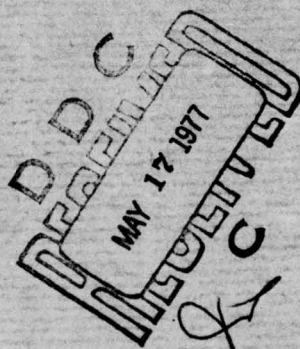
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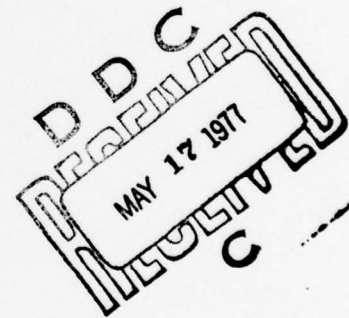
Assembly of Behavioral and Social Sciences

SPEECH UNDERSTANDING AND AGING

Report of Working Group 75

Committee on Hearing, Bioacoustics and Biomechanics
Assembly of Behavioral and Social Sciences
National Research Council, Washington, D.C.

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James N. Pickett, Moe Bergman,
Charles Berlin, John Fletcher
Ira Hirsh

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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Committee on Hearing, Bioacoustics and Biomechanics

Working Group 75 - Speech Understanding and Aging

<u>Members</u>

James N. Pickett, Chairman
Gallaudet College

Moe Bergman
Hunter College

Charles Berlin
LSU Medical School
Kresge Hearing Research Lab.

John Fletcher
Dept. of Otolaryngology and
   Maxillofacial Surgery
University of Tennessee Center
   of Health Sciences

Ira Hirsh
Central Institute for the Deaf

Harry Levitt
City University of New York

Harold Schuknecht
Massachusetts Eye and Ear Infirmary

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CHABA WORKING GROUP 75

SPEECH UNDERSTANDING AND AGING

It is commonly observed that speech understanding declines with advancing age. A major factor is the aging of the biological mechanisms of hearing, a phenomenon classically termed presbycusis. These changes often begin early in life and usually progress slowly so that significant dysfunction may not occur until later in life. The hearing losses caused by aging are always bilateral and usually symmetrical. They appear to be genetically determined, strongly influenced by heredity. In addition to the effects of aging processes, the auditory system is susceptible to age-accumulated damage from other sources, such as noise exposure and general systemic diseases.

The purposes of this report are to summarize the research data on speech understanding as a function of age, particularly as to their predictive value, and to recommend needed research on this problem. It is a problem of both fundamental and practical importance. Findings in this field can be used to improve our basic knowledge of auditory processes in speech communication and to better serve the communication needs of the elderly population. In addition, the data are of value in occupational medicine for determining the probable contribution of age to communication deficiencies, the proper compensation for industrial noise exposure, and the certification of safety-risk employees, such as aircraft pilots.

Some of the audiometric studies of presbycusic hearing have included measures involving speech understanding, such as speech reception threshold, word discrimination tests yielding a score of percent words heard correctly, and sentence reception. We review the recent literature on speech understanding and age covering the effects, in combination with age, of such well-known variables as competing noise, signal distortions, and redundancy of test materials. In addition, two newly-studied factors are the language background of the listener and short-term memory. Previous approaches to the task of prediction are described. As will be seen in our discussions of the experimental data, the factors in the aging of speech understanding are rather complex, and the data cannot be rationally integrated at this time. Even a straight-forward population-statistics approach to deriving predictive curves cannot be supported because of the lack of sufficiently extensive testing of the primary factors.

Anatomical studies of the cochlea and cochlear nerve in presbycusis indicate four general types (Schuknecht, 1974):

1) Sensory Presbycusis, due to atrophy of the transducer cells (hair cells) in the basal portion of the Organ of Corti, showing abrupt high-tone loss and little effect on speech understanding;

2) Neural Presbycusis, due to progressive atrophy of cochlear nerve fibers related to general aging process in the nervous system, showing a more serious loss of speech understanding than would be expected from the pure-tone audiogram;

3) Strial Presbycusis, due to atrophy of the stria vascularis, genetic, showing a flat audiogram with good speech understanding up to 50 dB loss, abnormally sensitive intensity discrimination (positive SISI), but no tolerance problem;

4) Cochlear Conductive Presbycusis, presumed due to a change in stiffness of the basilar membrane, showing a linearly sloping conductive loss with good speech understanding under proper amplification.

These four types of pathology may occur in more or less pure form or in combinations.

Gaeth (1948) was one of the earliest to call attention to an aging effect in understanding speech. In the mid-fifties, Pestalozza and Shore (1955) reported an experiment supporting Gaeth's findings and one year later Bocca and Calearo (1956) introduced the use of time-compressed speech to explore central pathology in presbycusis. Since then there have been a number of studies which show that the perception of speech is poorer in older persons than in younger persons matched for audiometric hearing level, either normal or impaired. Studies using a fairly large number of subjects and covering an extensive age-range depict the decrement in performance on speech-understanding tests as a curve based on the average scores of groups of subjects (Ss) in age decades from the decade 20-29 and older (Jerger, 1973; Bergman, 1971), or upon data from increasingly elderly groups of Ss (Goetzinger et al, 1961).

A few attempts have been made to arrive at mathematical regression curves which express the expected effect of age on speech understanding (Jerger, 1973). A difficulty in attempting to develop such prediction curves at this time lies in the many variables which differ between studies as to procedures and data reporting. Some of these variables will be identified and discussed in this report.

RESULTS OF MAJOR STUDIES

Goetzinger et al (1961), studied 90 non-clinical Ss 60-89 years old, listening at their preferred levels. With hearing loss held constant there was a significant relation between chronological age and word-discrimination scores for difficult word-material (Rush-Hughes recording of PB words), but not for easy material (W-22 recordings).

Harbert, Young and Menduke (1966) found differences of 10 to 20 percent in understanding scores which increased between presbycusic Ss, congenitally deaf Ss with similar hearing loss, and "normals." The presbycusics also showed a relatively greater deficit when listening to narrow frequency bands of speech at a low frequency, a higher frequency, and with the two bands combined. Punch and McConnell (1969) obtained performance-intensity functions for the phonetically balanced one-syllable words (CID W-22 lists) on two older age groups. Some of the Ss were selected from clinic files. One group had little hearing loss and the other group had mild to moderate hearing loss. The functions for these two groups were compared with the normative functions for young listeners. They found the functions for the older groups displaced 20 to 25 dB

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to the right (requiring higher intensities for equivalent scores).

Blumenfeld et al (1969), used the Fairbanks Rhyme Test (one-syllable words used in closed sets of six words) on a non-clinic population. They found that performance tended to decrease with age, but the correlations were much higher for the Ss over age 60 (r = .58) than below that age (r = 0.14). Similarly, Feldman and Reger (1967), also on a population not drawn from a clinic, found a decline of 5%-points in PB word scores per decade of age, over the range 50-89 years. They argue that the severe "phonemic regression" described by Gaeth (1948) and supported by Pestalozza and Shore (1955) "is not typical of the aged as a whole, but characterizes that segment of the elderly population seen in the clinical setting." This result and conclusion is also supported by a study of Hallerman and Plath (1971) using German words and measuring the maximum obtainable scores. The Ss of the Hallerman/Plath study showed the typical age effects on the pure-tone audiogram and a corresponding shift upward of the performance-intensity function with age but there was no significant decline with age in the maximum score obtainable at optimum listening level.*

Bergman (1971) screened his Ss against ear disease and noise exposure, and studied no Ss with hearing loss greater than 35 dB except at 4kHz where 45 dB was the maximum loss accepted. He presented the CHABA sentences, as revised by Harris; these are short simple sentences dealing with everyday situations. Tests were given to 282 Ss through earphones at telephone level (81 dB); there was little decrement in percent correct understanding from the 3rd to the 8th decade, but a more substantial decline for the 80-89 year-old Ss. These results were then used as a reference for studies in which the same sentences were distorted and competed. The literature does not seem to include other reports on aging effects in the under-standing of uncompeted and undistorted sentences. The relative lack of an aging effect for simple undistorted communication is consistent with other studies in which the aging effect is shown to be pronounced only for low-redundancy material and not for high-redundancy material like that of the "everyday" sentences of the CHABA lists.

Jerger (1973) reviewed his clinic files (4,095 ears of 2,161 patients of all ages, including almost 800 in the 7th age decade) and plotted the average PB max scores for the third through the ninth decades; he fitted a prediction curve having an exponential decline in score as a function of age.

Bergman et al (In Preparation), have plotted the results of Bergman (1971) using the Arc Sine transform of percent correct response. The

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*Hallerman and Plath also report no correlation between age and pure-tone frequency discrimination, using the "warble" or frequency-modulating tech-nique. König (1957) tested a similar non-clinical population, using pairs of tones to which the subject reported whether the second tone was lower or higher in pitch. This task showed a decrement in pitch discrimination with age which might have involved a central factor in memory for the sensation-changes to be described as "lower" and "higher".

purpose of the Arc Sine transform is to normalize the variation in statistical significance-interval with performance level which is present when performance is expressed in percent correct response (see Brownlee, 1965). The transform appropriately compresses differences in the highest and lowest range of performance to be equal in significance to the differences in the middle range. In Fig. 1 we have plotted some of Bergman's 1971 data and data from comparable Ss of Jerger (1973). The Jerger data plotted in Fig. 1 are those of his groups having only mild hearing losses. It will be seen that the two curves of gradual decline of speech-understanding with age are parrallel but with the sentence data of Bergman et al higher than for the isolated word scores of Jerger. However, the age decline in understanding the sentences is much steeper for competing and distorting conditions of reception, with interrupted speech (8 ips) being exceptionally difficult at age 40 and beyond.
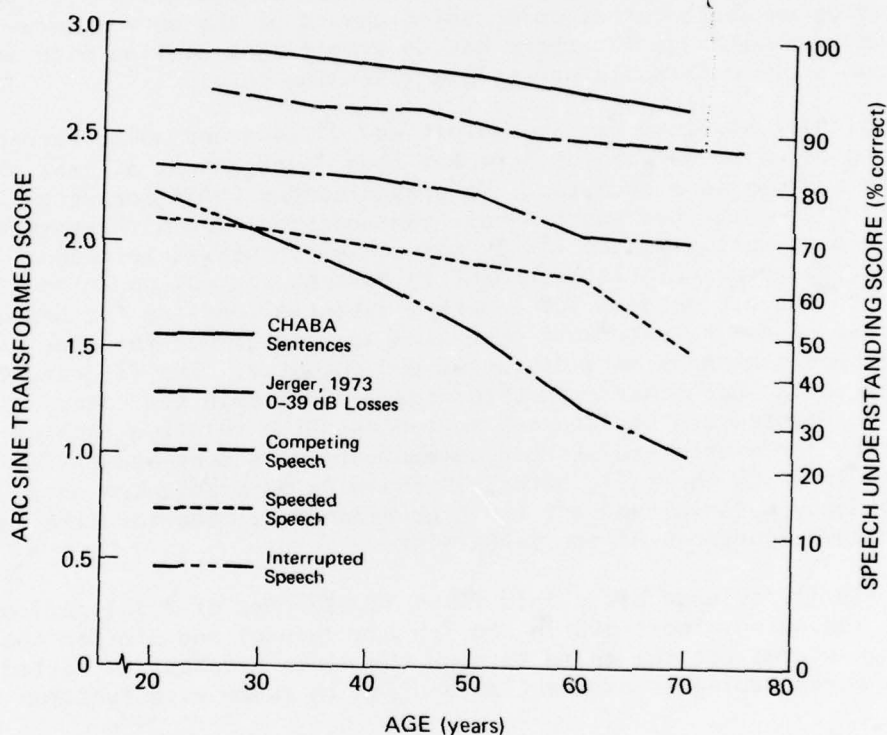
Bergman et al., 1976

Fig. 1. Group measures of speech understanding as a function of age based on the studies of Jerger (1973) and Bergman et al (1976). The points plotted for the Jerger study are averages, which we derived from his Fig. 1, for his four groups with the least hearing loss. This selection of Jerger's data was made in order that his data be comparable to that of the Bergman, et al, Ss who had been screened against severe loss. All understanding scores (% correct) were converted by arc sine transform (Brownlee, 1965) according to the formula $y = 2 \text{ arc sine} \sqrt{P}$. This transform results in relatively constant statistical difference-criteria at all levels of performance. Corresponding percent-correct scores can be read from the right-hand scale. All of the Bergman, et al, data are for CHABA sentence material. The Jerger data are for the individual maximum-obtainable scores with isolated one-syllable phonetically-balanced (PB) words.

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AGING AND UNDERSTANDING DEGRADED SPEECH

Most of the studies agree that the effects of aging on the understanding of speech are most clearly demonstrated when the listening task is made more difficult. Many types of alteration of the speech signal and its acoustic environment have been investigated. Each type is discussed below under a separate heading.

Temporal Interruption. In testing this factor the speech signal is periodically interrupted by electronic switching (Bocca and Calearo, 1956); Teatini, 1970; Harris, J.D., personal communication; Bergman, 1971) or the signal may be periodically switched from one ear to the other (Teatini, 1970), or it may be periodically masked by bursts of noise (Calearo, Teatini and Pestalozza, 1962). The latter authors report that speech understanding in the presence of interrupted masking is very different from that obtained from interrupted speech.

Among the earliest to use interrupted speech, Bocca and Calearo (1956) tested Ss over the age of 75 who had no special hearing problem and found their performance inferior to that of young Ss.

Bergman (1971) found that interrupted speech (interruption rate of 8 interruptions per second) yielded the most dramatic decrement in speech understanding with aging, of the six sensitized speech tests he studied, with a significant drop appearing as early as the fifth decade (See Fig. 1). After comparing his results with the "normative" functions for interrupted speech developed by Licklider and Miller (1951, p. 1063) he suggested that the effect of aging on the perception of interrupted speech appears to be similar to a reduction of speech on-time.

Antonelli (1970) provides curves comparing the performance of young vs older Ss as a function of various interruption rates. Again, the older Ss scored much lower than the younger Ss, particularly under the more-difficult interruption rates of 5 and 8 interruptions per second.

Time Scale Alteration. Here the speech signal is either speeded or slowed. Speeded speech is usually produced by time-compression, a sampling and playback technique which compresses signal duration without altering the frequency-components; slowed or expanded speech is produced by a similar sampling but with reiteration of samples to stretch the signal without altering the frequency-components. It should be noted that time-compressed speeded speech always has a portion of the signal information removed.

Bocca and his colleagues (Bocca and Calearo, 1956; Calearo and Lazzaroni, 1957; Bocca and Calearo, 1963) used speech speeded to 2-1/2 times the normal speed of 140 word/minute. Calearo and Lazzaroni reported results with speeded speech obtained by three methods: 1) an extraordinarily fast talker, 2) fast tape playback, and 3) time-compression. They found very great differences between young listeners, who required only a 10dB increase in the presentation

level above threshold to achieve a given score at the high speed and older Ss who required a 15 to 40 dB increase for a moderately high speed and could not understand much of the 2-1/2 times normal speech at any intensity.

Sticht and Gray (1969), used a small sample of Ss (7 for each subgroup) and W-22 word lists; these are phonetically balanced lists of one-syllable words; they found a significant interaction between age and time-compression ratio (using 36, 46, and 56 percent time-compression). The scores of the older Ss deteriorated, relative to the younger Ss, as the amount of compression increased. They suggest that in aged persons the sensory channels process a reduced amount of information and cannot, therefore, handle a rapid input as well as young persons.

Jerger (1973) subjected his Synthetic Sentence Identification Test to 50% time-compression and presented it in the presence of ipsilateral speech competition, to three groups of listeners: young normals, presbycusic patients, and young adult patients who were matched with the presbycusics for average hearing level. The latter two groups showed severe performance breakdown on this task, which was very difficult even for the normal young group.

Luterman et al (1966) tested three groups of listeners; 1) very old (mean age 84.7 years) Spanish-American War veterans, 2) a normal young adult group, and 3) young adult Ss with "mild high-frequency hearing losses" which closely matched the hearing of the war veterans. They listened to recordings of W-22 word lists that were either time-compressed or expanded up to 20%. The old Ss performed poorest; under 20% compression; for example, they scored 64% correct vs 76% for the young hearing-impaired, and 88% for the young normals. None of the groups' performances improved with expanded speech as the signal. Bergman (1968), using the CHABA sentences speeded to 2-1/2 times normal, found only mild decrement in performance up to age 60, with moderately greater changes in the 70s (See Fig. 1).

Band-limited Speech. Both word and sentence material have been subjected to low-pass and band-pass filtering in some studies.

Teatini (1970) progressively attenuated the bands 400-800, 1600-3200, 3200-6400 Hz, creating an effect roughly similar to a 500-Hz low-pass filter. The filtered speech was then used by Antonelli (1970) at various presentation levels to derive performance-intensity curves for old vs young Ss. The older Ss performed more poorly.

Bergman (1968) subjected the CHABA sentences to band-pass filtering of 500-800 Hz and 1800-2400 Hz and presented these simultaneously, one to each ear. The decrement with age decades was only slightly greater than for speeded speech, and considerably less than for interrupted or for overlapping, competing speech material.

Binaurally Competing (Dichotic) Speech. Katz (1962) devised a test in which pairs of words are presented, simultaneously, one member of the pair to each ear, requiring the S to report both words; Brunt (1972) reports that results using this test on adults over 50-55 years deviate from normal but noted that this report, based upon a study of Balas (1962) must be interpreted with caution.

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Bergman (1971), in a study of 282 Ss from 20-89 years, found this dichotic speech test to be second only to the interrupted speech test in revealing sharp decrements in speech understanding with age. The difference in performance scores between the oldest and youngest groups was 54 percentage points. Clark and Knowles (1973) also report a decline with age in dichotic listening, attributable mainly to errors in reporting from the mean non-dominant ear which were not due to hearing loss.

Reverberated Speech. Schubert (1958) studied aging and perception of nonsense syllables presented by mixing a non-reverberant recording and a reverberant recording from a room having a five-second reverberation time. Between the age groups 40 and 60 years, scores fell from 100% correct to 83% correct for the unreverberated speech; the corresponding scores with a small amount of the reverberated signal added (at -10 dB re the unreverberated signal) were 93% and 62% correct. Bergman (1971), using a 2-1/2 second reverberation time and CHABA sentences, corroborated Schubert's findings of progressive deterioration, with age, in the perception of reverberated speech. Bergman (1971), compared his results with curves published by the American National Standards Institute (1969) on the relative effects of various reverberation times and suggested that the decrease of scores with age, in his study, was equivalent to a progressive increase in the reverberation time.

Degraded Speech vs Task Complexity. As noted by Olsen (1965), the complexity of the task shows greater relationship to the poorer results obtained on older Ss with degraded speech tests than the specific factors in the test, such as speed, frequency-filtering, etc. In all of the foregoing, however, there is some evidence that interrupted speech is one of the most sensitive tests of aging effects.

LISTENERS' LANGUAGE BACKGROUND

Our standard speech-understanding tests employ the language and vocabulary of the dominant culture. Obviously the older age-groups in a population may contain persons with mis-matches between the original language of the S and the language of the test material. In a study of this effect, using the data of his 1968 study, Bergman found significantly poorer performances on degraded speech in 60 to 69 year old Ss whose first language was other than that of the test material (English), compared with Ss of the same ages whose native language was English. This result occurred despite the fact that the non-native Ss had used English for many decades. Under certain difficult listening conditions the non-native listeners scored 12 to 17% lower. A similar result has been found with Hebrew test material in older subjects whose adopted language was Hebrew but whose first language was not Hebrew (Bergman, In Preparation). These findings strongly suggest that statistical predictors of speech perception in aging should take into account the language backgrounds of the population of concern.

REDUNDANCY AND SHORT-TERM MEMORY

As used in reports on speech perception in clinical populations, redundancy usually refers to the availability of extra cues in a message. To the degree that the message in whole or in part is predictable the

message is redundant. Redundancy permits correct perception of a message that contains errors, whether the errors originate in the auditory processes of the listener or in extrinsic factors, i.e., factors in the message itself or in its transmission to the listener (Berruecos, 1970).

It is generally agreed by investigators of hearing and aging that a reduction in message redundancy is more disabling to the older listener than to a younger one. This agrees with studies of short-term memory, in which a simple task, e.g., auditory and visual digit span, is involved. But when there is a competing or otherwise interfering condition, the required simultaneity of more than one activity is apparently increasingly disruptive with advancing age. (Sparkman, cited in Welford, 1958); Clark and Knowles, 1973).

Craik (1968) reports that "there is mounting evidence that perception and short-term memory are mediated, at least in part, by the same mechanism", and that older persons may suffer decline in their ability to perform these two functions either simultaneously or in the required temporal sequence. Craik (1965) concluded that age deficits in recall of learned lists of words indicated increasingly faulty retrieval with age.

The roles of redundancy and short-term memory in speech perception as employed by older vs youngser Ss are still to be explored. An important task variable, directly affected by short-term memory, is that of sentence length. Mayer (1975) found a negative correlation between sentence length and intelligibility scores for the CHABA sentences; i.e., the average intelligibility score for each sentence decreased as sentence length increased. She also observed that the correlation was smaller for the younger as opposed to the older Ss; however, the magnitude of this effect was relatively small.

The form of one stage of memory store for speech perception is undoubtedly arranged according to phoneme categories. Stevenson (1975) found that response-latencies and phonemic confusion patterns in some elderly listeners seemed to consistently imply a reduced inventory of available phoneme categories for response.

PREDICTIVE FUNCTIONS OF SPEECH-UNDERSTANDING VS AGE

We turn now to a description of the few attempts that have been made to arrive at a predictive curve describing the "normal" deterioration of speech-understanding with age.

Kinchcliffe (1962) offered an equation for the loss in sensitivity for pure tones with age, as follows:

$\log (\emptyset - \emptyset_k) = 0.032A - 5.173$ where $\emptyset$ is threshold sensitivity in dynes/cm^2, $\emptyset_k$ is a reference intensity depending on frequency, and A is age.

Jerger (1973), citing this, offers his own equation for relating PB max scores (NDRC lists) to age:

$\log (y-100) = a + 0.015x$ -- where y is the PB max score and x is age in years.

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Feldman and Reger (1967) administered pure tone tests, speech-under-
standing tests, and tests of tactile and auditory reaction-times; they
report that 72% of the variance in the speech scores could be accounted for
on the basis of the thresholds at 500 and 1000 Hz combined with tactile and
auditory reaction times. They report an increase in impairment of speech
discrimination over age 50 of 5% per decade. Since there was only a 5%
difference in scores between their young control group (ages 20-28) and
the 50-59 year old Ss, they conclude that speech-understanding ability is
relatively stable (for words given in quiet) between 20 and 50 years of age.
However, it should be noted that the W-22 test is a very easy one and that
more-difficult test material may be required to differentiate discrimination
in the 20-to-50 years range.

Their findings on sensitivity for spondees (SRT) showed a 15.8 dB shift
(from the young controls as a reference) for the 50-59 group, 22.2 dB for
the 60-69s, 33.6 dB for the 70-79 age group, and 38.3 for the 80-89 year
olds. They showed a correlation-coefficient of 0.64 between age and SRT,
and a correlation of -0.56 between age and PB scores, both significant at
the 0.01 level. The variable that was most predictive of the discrimina-
tion score was the threshold at 1000 Hz (correlation of -0.64).

The foregoing prediction-functions of speech understanding vs age are
limited in applicability in that they do not reflect speech-understanding
under realistic conditions using continuous meaningful material, such as
sentences, under various conditions of distortion and competitive signals,
both noise and speech.

AGING AND NOISE INTERFERENCE

Since everyday speech communication often takes place in noisy situa-
tions, it is important to know whether age introduces a differential deterior-
ation of speech understanding under noisy conditions.

Various types of noise have been used in the normative and clinical
studies of speech understanding in noise. Some investigators have used
broad band white noise. An example, using the Modified Rhyme Test, is the
study of Dirks and Wilson (1969). Objections to this noise are that it
lacks resemblance to noises of everyday situations and that it is too dis-
similar from the speech signal in semantic attributes and in temporal
patterning.

Other noises used include environmental sounds, such as cafeteria
noise (Corliss et al, 1960; Cooper and Cutts, 1971), cocktail party noise
(Groen, 1969), and competing speech signals, such as competing sentences
(with single test words as the primary signal--Carhart, 1965; Carhart and
Tillman, 1970) or continuous discourse (with synthetic sentences as the
primary signal--Dirks and Wilson, 1969; Trammel and Speaks, 1970; Dirks
and Bower, 1969). One study employed speech-noise from two lateral sources
with the signal source in the center, testing a population with a large
range in age and (presumably) age-correlated noise exposure from years of
work in heavy industries (Lindeman and Van Leeuwen, 1967). Other variations
of the use of speech-noise include changing the number of talkers or com-
bining this with other noise (Carhart and Nicholls, 1971) and changing the

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competing speech from forward to backward (Dirks and Bower, 1969; Trammel and Speaks, 1970). When a large number of voices is used, the acoustic distribution of speech is retained and the semantic force of the competing messages is not a factor because the noise is now a babble in which no words can be distinguished. This also reduces the time windows, so that the masking noise, though speech-like, is relatively continuous.

The type of competing material apparently influences the slope of the performance-intensity function, shallower functions obtaining when the masker is white noise rather than speech spectrum noise. However, use of a running speech-mask from a single talker, who is the same as the target-talker speaking synthetic sentences, can produce shallow functions relative to white noise (Speaks and Karmen, 1968; Speaks, Karmen and Benitez, 1967).

Speech understanding in noise has been reported to be more variable than reception in quiet, for both normal and hearing impaired Ss (Cooper and Cutts, 1971); Kreul et al (1968) suggest that the variability among listeners becomes less with increasing signal-to-noise ratios.

There have been a number of studies of the effects of age on speech understanding in noise. Ross et al (1965), found no significant correlation between age and speech-discrimination with easy materials (W-22 word-lists) in white noise. Smith and Prather (1971), on the other hand, found that older Ss (with good audiometric hearing) performed 10 to 25 percentage points poorer than younger Ss on the perception of consonants at various S/N ratios and at various sensation levels.

Blumenfeld et al (1969), found decreasing Rhyme Test scores in broad band white noise at a S/N ratio of 0 and sensation level of 35, as age increased, particularly over age 60, but the correlations between scores and aging were higher in quiet than in the noise condition.

Workers at the Northwestern University Auditory Research Laboratories have pursued a number of studies of the effect of competing intelligible speech on the perception of a target speech message. They label such interference "perceptual masking", defined as "an increased interference with the understanding of one speech signal which appears when a complex /noise/ background contains speech among its components" (Carhart and Nicholls, 1971). A manipulated variable was the relative binaural phase conditions of the target test material (spondees) and the maskers. Also, the number of competing voices was varied. They concluded that older individuals "tend to have reduced capacity for handling those complex listening situations that include speech."

In a further study at Northwestern, the spondee reception thresholds of normal-hearing elderly listeners were measured as an index of the extent to which the aged auditory system can make use of interaural phase and time-delay to enhance reception under conditions of competing noise and competing speech (Tillman et al, 1973). The elderly listeners showed reduced ability, compared with young listeners, to profit from interaural time-delays which simulated a competing talker on each side with the target message in the center. The magnitude of the reduction in masking level difference was on the order of 2 dB.

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Jerger (1973) reports that older Ss showed considerable breakdown in speech perception when required to identify synthetic sentences in the presence of ipsilateral speech competition.

Bergman (1968), with 189 Ss found relatively small age decrements in the perception of CHABA sentences over two competing intelligible talkers at a S/N ratio of -5 dB.

Mayer and Levitt (In Preparation) found a definite decline in speech understanding in noise as a function of age. Two types of environmental noise were used, traffic noise and subway noise, as they were recorded in New York. The test material was sentences recorded from a male speaker and a female speaker equated for signal level. There were 160 listeners. Composite curves of the results are shown in Fig. 2 which is based on the original data points as fitted by polynomial functions of reception vs age.
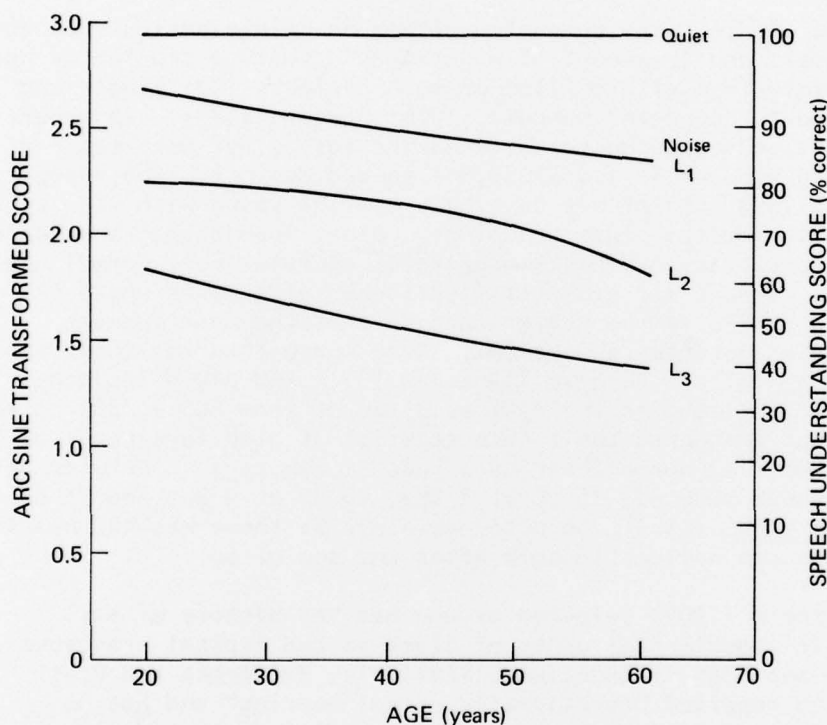

Fig. 2. Speech-understanding as a function of age in quiet and in noise. The curves plotted are based on polynomial functions fitted to the data of Mayer and Levitt (In Preparation), who tested 160 Ss listening to easy speech materials in quiet and in recorded subway and traffic noise with the noise set at three levels, L1, L2, and L3. Age had no effect on understanding the speech in quiet but a relatively small amount of noise, L1, which reduced understanding only 5% for the young Ss, caused a further progressive reduction (up to 15%) with increasing age. The highest level of noise, L3, reduced young Ss' understanding scores to about 60% while the oldest Ss were reduced to about 40% understanding.

Tests were carried out in quiet and with noise at three different levels, labelled L1, L2, and L3 in the Figure. Although there was no age-decline in performance in quiet, there is a definite age-decline when listening in noise.

METHODOLOGICAL PROBLEMS

There are problems of population selection and test materials which make it difficult to compare results from different studies. The following section reviews these effects.

Population Selection. A very important problem is the selection of an experimental population which will reflect changes in speech understanding specifically as a function of age. Should the Ss meet audiometric criteria of normalcy established for young adults or should they be representative of their age groups?

Some previous studies were conducted either on clinic patients as they applied for diagnosis and treatment of a noticeable hearing problem or were drawn retrospectively from clinic files of such patients (Goetzinger and Rousey, 1959; Harbert, Young and Menduke, 1966; Jerger, 1973). In other reports the Ss were acknowledged to have hearing losses but were matched, by audiograms, with younger Ss (Luterman, Welsh and Melrose, 1966; Jerger, 1973). Jerger analyzed some of his data by comparing young with old Ss within 10 dB mean audiometric loss groupings. Other investigators selected Ss who could meet arbitrary audiometric criteria of relatively normal hearing. For example, Carhart and Nicholls (1971) used elderly Ss whose SRT was better than 50 dB SPL in the better ear, so that the mean spondee thresholds for their poorer ears were only 10 dB worse than for their control group of young adults. Bergman (1968 and 1971) and his associates set the audiometric maximum for their Ss at 35 dB HL from 500 - 2000 Hz and 45 dB at 4000 Hz but presented their test material at high levels (81 dB SPL). Antonelli (1970) required normal hearing of his Ss (average thresholds of 10 dB from 125 through 1000 Hz, 15 dB at 2 kHz, 20 dB at 4 kHz and 35 dB at 8 kHz. Goetzinger et al (1961), selected as older Ss those who had hearing losses which had become noticeable only after the age of 50.

Feldman and Reger (1967) selected Ss who had "no history of ear disease," but their experimental group of older sS had typical presbycusic audiograms at mid and high frequencies. Similarly, Hallerman and Plath (1971) chose Ss who reported "functionally normal hearing" and had no history of excessive noise exposure or medical conditions that would affect hearing, but nevertheless turned out to have typical presbycusic losses with increasing age.

Horizontal vs Longitudinal Age Samples. Another subject-selection problem is the comparison of populations of Ss who are presently 20-29 with those who are 60-69 instead of doing longitudinal studies in which Ss are tested repeatedly as they age. It may be argued that horizontal sampling does not accurately reflect aging effects since the normative (young Ss') data includes Ss who will not survive into the older decades, i.e., there is progressive screening of Ss for various reasons. Bergman, et al (1976) have published the results of longitudinal studies conducted three and seven-and-a-half years after the initial tests on their Ss (Bergman, 1971).

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The close agreement between the results of the earlier horizontal sampling
study and those of the longitudinal study confirms the aging effects in
the perception of speech under less-than-optimal conditions as seen in
Fig. 1.

Test Materials. The test materials employed to test speech under-
standing have varied from closed-set tests, such as the 16 consonants used
by Smith and Prather (1971) and the Fairbanks Rhyme Test (Blumenfeld et al,
1969), through words scored in terms of number of phonemes correct (Linde-
man and Van Leeuwen, 1967), PB words (Luterman et al, 1966; Harbert et al,
1966; Jerger, 1973; Sticht and Gray, 1969), and finally sentences (Antonelli,
1970; Bergman, 1971 ⎣CHABA sentences⎦). These materials were sometimes em-
ployed in new applications, e.g., Goetzinger et al (1961), compared the
difference scores obtained on a standard vs a more difficult recording
(Rush Hughes) of PB words for young vs older Ss, while Katz (1962) used
overlapping pairs of spondee words in a dichotic competition test.

Stevenson (1975) has developed automated methods of speech audiometry
and of phoneme identification in closed sets. The procedures are adaptive
in test sequencing and response latencies are recorded. The latencies and
phoneme-confusion patterns of Stevenson's elderly Ss appear to be diagnostic
of individual deficiencies in perceptual processing of speech.

The literature on speech perception indicates that different talkers
can cause a shift in the performance-intensity function (Silverman and
Hirsh, 1955, for PB words; Kreul et al, 1968, for the Modified Rhyme
Test).

There do not seem to be available any data relating the effects of
different voices on speech perception in aging. One preliminary study has
been conducted at Hunter College, indicating a decrement in speech percep-
tion, for older Ss, going from a male talker, to a female talker, to a
husky male voice, and finally to a whispered voice, but normative data have
not yet been established for comparison. Preliminary findings suggest that
the perception of speech, in aging, is at least partly dependent on the
voice of the talker.

SUMMARY AND RECOMMENDATIONS

Our review of aging and speech understanding has clearly shown that
the elderly population experience severe deficits under certain conditions.
These deficits appear to be large enough to cause economic and social
problems for the middle-aged and elderly adult in his everyday life.
Furthermore, in some occupations, for example, aircraft pilots, air traffic
controllers, and in noisy occupations in heavy industry, there are safety
problems with regard to ability to understand speech.

Standard tests of physical health should include tests of ability to
hear and understand speech as well as the routine pure-tone audiogram. The
speech tests should involve realistic conditions of noise and message
redundancy.

There exists an obvious need for standardization of materials and procedures, and for the establishment of norms so that the effect of aging can be known and accounted for.

There are many factors, other than aging and specific diseases of the ear, that may act to reduce hearing. One primary factor may be noise in the environment; others are general systemic bodily conditions, such as circulatory and metabolic conditions, and drug usage. Any or all of these factors might be expected to cause an accumulated effect on speech-understanding with age. To our knowledge there are no studies of these factors.

The most important need is for a large-scale study dealing with the problem of noise exposure over the years of life, subsequent speech-discrimination loss, and aging. One might take a purely statistical approach using large numbers of Ss grouped by age, with occupational sub-groups that would be expected to have average noise-exposures of different amounts. The little-exposed age-groups would be the controls for the effect on speech discrimination of the increasing general physical deficits with age. Control of contaminating interactions would be necessary to the extent that occupational subgrouping is selective on other possible variables, such as diet, language-background, sex, race, and genetic make-up.

Research in behavioral gerontology has demonstrated general central-processing deficits that increase with age (Welford, 1958; Botwinick, 1973). There can be little doubt that these deficits would affect the scores of mid-life and elderly Ss in speech-understanding tests. It seems unlikely that sufficient predictive accuracy can be obtained without partialling out some of the variability in central processing deficits. (We doubt that speech-relevant auditory tests can be developed that will not be affected by central processes). What is needed, therefore, are studies of speech understanding together with measures of central deficits that use visual and tactile patterns that would not involve hearing.

The basic bodily factors contributing to the aging of hearing have not been extensively studied. Auditory perceptual data should be correlated with physical health status in studies of the elderly and their temporal bones should subsequently be studied histologically.

At the periphery (cochlea and cochlear nerve), there are well documented patterns of degeneration from aging, involving specific cell types. The peripheral losses in auditory sensitivity and discrimination are clearly expressions of the types of associated morphological change. In some cases the types occur in almost pure form and in other cases in combination. Thus, ears showing only atrophy of the stria vascularis, exhibit threshold losses characterized by flat audiometric patterns but excellent speech discrimination scores. These ears have normal or near normal populations of sensory and neural units and are, therefore, capable of normal stimulus coding. Another type of pathological change of aging which may also occur in nearly pure form is degeneration of the cochlear neurons. Such ears, deficient in neural transmission channels, characteristically show severe losses in speech discrimination and comparatively less loss in auditory threshold.

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Any study of speech-discrimination as a function of age, must take these pathological variables into account. The deafness of aging is not caused by a uniform type of degenerative change with the only variable being the magnitude of change. There are at least four distinct types of dysfunction based on changes at the periphery alone. Each would be expected to behave differently in receiving speech under conditions of background noise and to react differently to sound-amplification.

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